Hydrology and Water Quality near Bromide Pavilion in Chickasaw National Recreation Area, Murray County, Oklahoma, 2000

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By William J. Andrews and Steven P. Burrough[1]

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U.S. Department of the Interior

GALE A. NORTON, Secretary

U.S. Geological Survey

CHARLES G. GROAT, Director

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
Length		
inch (in)	2.54	centimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
Area		
square foot (ft^2)	929.0	square centimeter
square foot (ft^2)	0.09290	square meter
square mile (mi^2)	2.590	square kilometer
Volume		
gallon (gal)	3.785	liter
Flow rate		
foot per day (ft/d)	0.3048	meter per day
gallon per minute (gal/min)	0.06309	liter per second
gallon per day (gal/d)	0.003785	cubic meter per day
inch per year (in/yr)	25.4	millimeter per year

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F=1.8 °C+32$$

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C=(°F-32)/1.8$$

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 ˚C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

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ABSTRACT

The Bromide Pavilion in Chickasaw National Recreation Area drew many thousands of people annually to drink the mineral-rich waters piped from nearby Bromide and Medicine Springs. Periodic detection of fecal coliform bacteria in water piped to the pavilion from the springs, low yields of the springs, or flooding by adjacent Rock Creek prompted National Park Service officials to discontinue piping of the springs to the pavilion in the 1970s. Park officials would like to resume piping mineralized spring water to the pavilion to restore it as a visitor attraction, but they are concerned about the ability of the springs to provide sufficient quantities of potable water.

Pumping and sampling of Bromide and Medicine Springs and Rock Creek six times during 2000 indicate that these springs may not provide sufficient water for Bromide Pavilion to supply large numbers of visitors. A potential problem with piping water from Medicine Spring is the presence of an undercut, overhanging cliff composed of conglomerate, which may collapse. Evidence of intermittent inundation of the springs by Rock Creek and seepage of surface water into the spring vaults from the adjoining creek pose a threat of contamination of the springs.

Escherichia coli, fecal coliform, and fecal streptococcal bacteria were detected in some samples from the springs, indicating possible fecal contamination. Cysts of *Giardia lamblia* and oocysts of *Cryptosporidium parvum* protozoa were not detected in the creek or the springs. Total culturable enteric viruses were detected in only one water sample taken from Rock Creek.

INTRODUCTION

Platt National Park, now known as the Travertine District of the Chickasaw National Recreation Area, was established as one of the first national parks in 1902 (Gould and Schoff, 1939). The recreation area was deeded from local Native American tribes to protect 27 springs, which produced mineralized water with elevated concentrations of hydrogen sulfide, bromide, sodium, potassium, chloride, and other constituents. Water discharging from these springs has long been reputed to have therapeutic qualities, to the extent that doctors in the area wrote prescriptions for water from these springs. People traveled from considerable distances to drink and bathe in the water flowing from these springs in the early part of the 20th century. Some people in the area still consume mineralized water from the park and other local sources to treat health problems.

Bromide Pavilion, located near the main entrance of Chickasaw National Recreation Area (figs. 1 and 2), provided water piped from nearby Bromide (fig. 3) and Medicine Springs (fig. 4) for public consumption from the mid-1930s, when it was constructed by the Works Progress Administration, until the early 1970s. The pavilion had been one of the major attractions at the recreation area, drawing many thousands of visitors who filled bottles with water piped from these springs. Bromide Pavilion also was the major focal point for cultural activities, such as concerts, during the early part of the 20th century.

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Periodic detection of fecal coliform bacteria in water piped to the pavilion from the springs, low yields of the springs, or flooding by adjacent Rock Creek prompted National Park Service officials to discontinue piping of the springs to the pavilion in the 1970s.

Park officials would like to resume piping mineralized spring water to the pavilion to restore it as a visitor attraction, but they are concerned about the ability to provide sufficient quantities of potable water (Ron Parker, National Park Service, oral. commun., 1999). To address this concern, the U.S. Geological Survey conducted an investigation of spring yields, contamination by microbes, and potential mixing of water from Bromide and Medicine Springs with an adjoining portion of Rock Creek in 2000. The investigation was part of the National Park Service and U.S. Geological Survey Water-Quality Monitoring and Assessment Partnership Program.

Purpose and Scope

The purpose of this report is to describe the quantities and quality of water that may be obtainable from Bromide and Medicine Springs in Chickasaw National Recreation Area, as measured by water properties and the occurrence of selected fecal-indicator and disease-causing microorganisms in water samples collected six times between February and September 2000. Analytes included water properties, fecal coliform, fecal streptococcal, and *E. coli* bacteria. Microparticulate analyses or analyses of cysts and oocysts of *Giardia lamblia* and *Cryptosporidium sp.* and culturable enteric viruses were made in samples collected from the springs and the creek in February and July. Rates of recoveries of water levels in the springs after pumping ceased were analyzed to estimate yields from the springs. These data will be used by National Park Service officials to determine the potential for restoring piping of mineralized spring water to Bromide Pavilion.

Acknowledgments

The author thanks National Park Service personnel for assistance and encouragement provided during the course of this investigation. The author specifically thanks the following National Park Service personnel: Chief of Interpretation and Acting Chief of Resource Management Ronald Parker, Facility Manager Cal Myers, and Superintendent Gerard Baker for their assistance, support, and cooperation during sample collection.

DESCRIPTION OF THE STUDY AREA

Chickasaw National Recreation Area is in Murray County in south-central Oklahoma (fig. 1). The climate of the study area is subhumid, with most precipitation occurring as rainfall (Fairchild and others, 1990). Hanson and Cates (1994) reported that mean annual rainfall at the recreation area from 1919-87 was 38.29 inches, with a range of 19.54 to 60.86 inches during that period. Fairchild and others (1990) reported that evapotranspiration in the area averaged about 31 inches per year.

Several previous reports (Fairchild and others, 1990; Hanson and Cates, 1994; and Wikle and others, 1998) have characterized the hydrogeologic setting and the quality of water resources in the recreation area. Hanson and Cates (1994) reported on decreases in spring flows and pressure heads in the area resulting from a combination of climate change, continued lowering of pressure heads in aquifers by free-flowing artesian wells, and increases in other ground-water withdrawals in the area.

Hanson and Cates (1994) described land cover in the area as about 30 percent grassland, 30 percent woodland, 38 percent woodland-chaparral-grass, and 2 percent other. Prior to the 1890s, much of Oklahoma consisted of prairies covered by grasses and forbs, maintained by the subhumid climate, numerous grazing animals, and a natural fire cycle (Bidwell and Moseley, 1992). The Civilian Conservation Corps planted 800,000 plants in 1933, including 60 native tree species, among them the eastern red ceder, which has become invasive in the recreation area (Hanson and Cates, 1994; Bidwell and Moseley, 1992). Most trees are confined to stream valleys, with upland areas dominated by bunch grasses, cacti, and other xerophytes capable of withstanding droughts and extreme temperatures (Hanson and Cates, 1994).

Soils underlying the study area include those of the Garvin-Elandco Association, described as deep, nearly level to very gently sloping, moderately well-drained to well-drained clayey and loamy soils formed on alluvium, and those of the Kiti-Rock outcrop-Rayford Association, described as shallow to very
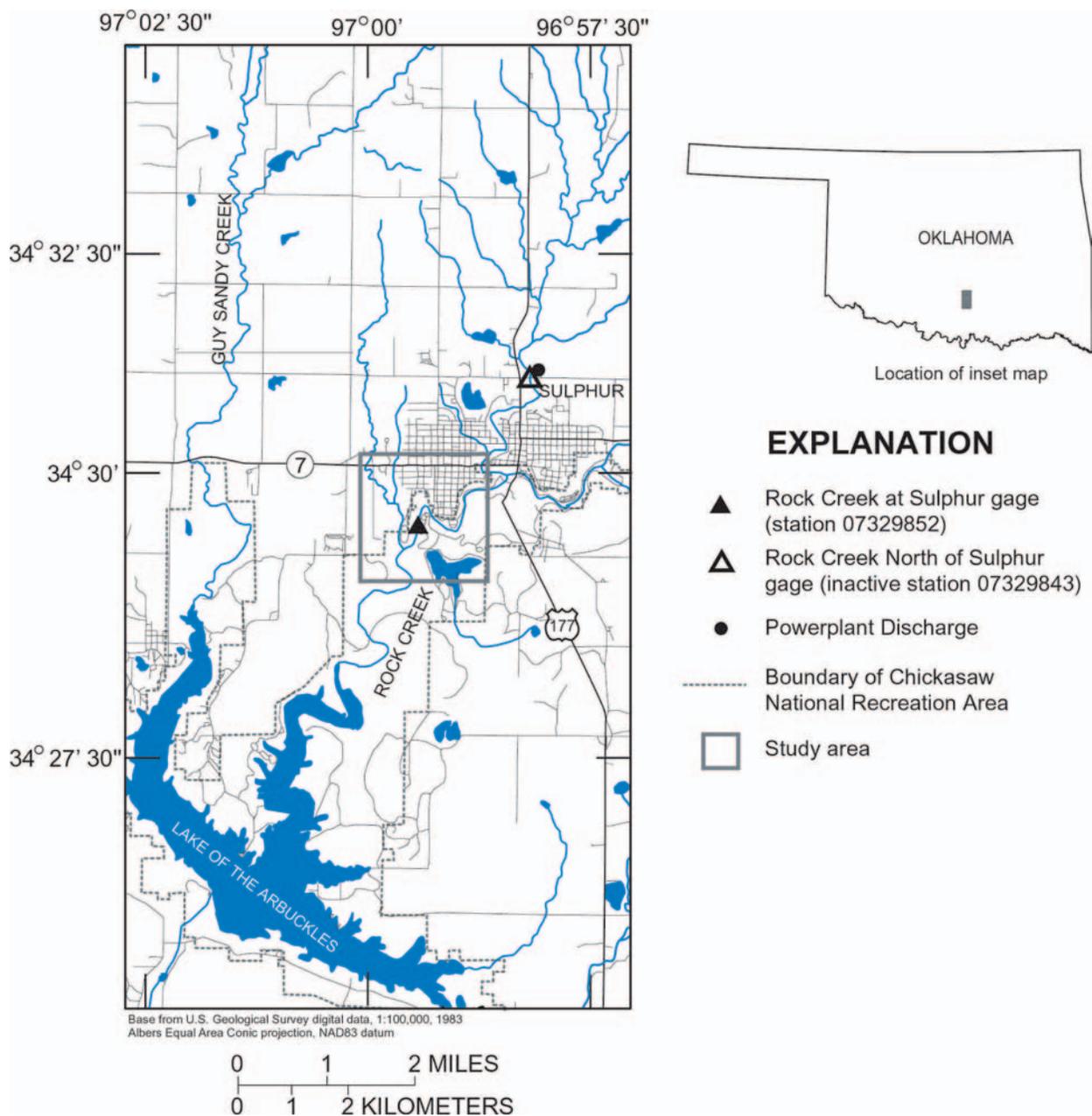
Figure 1. Location of the study area, Murray County, Oklahoma.
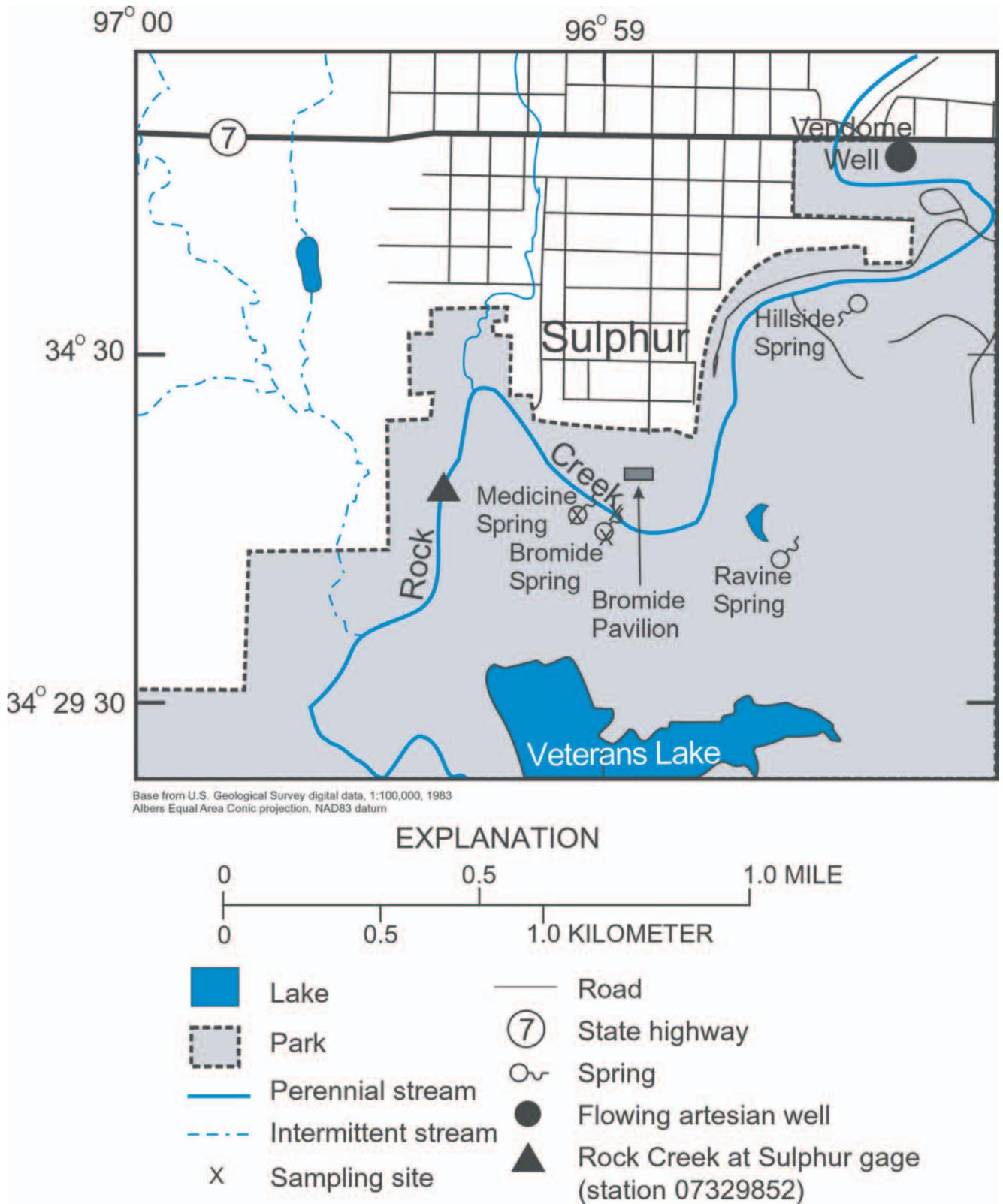
Figure 2. Location of study area in Chickasaw National Recreation Area, Murray County, Oklahoma.
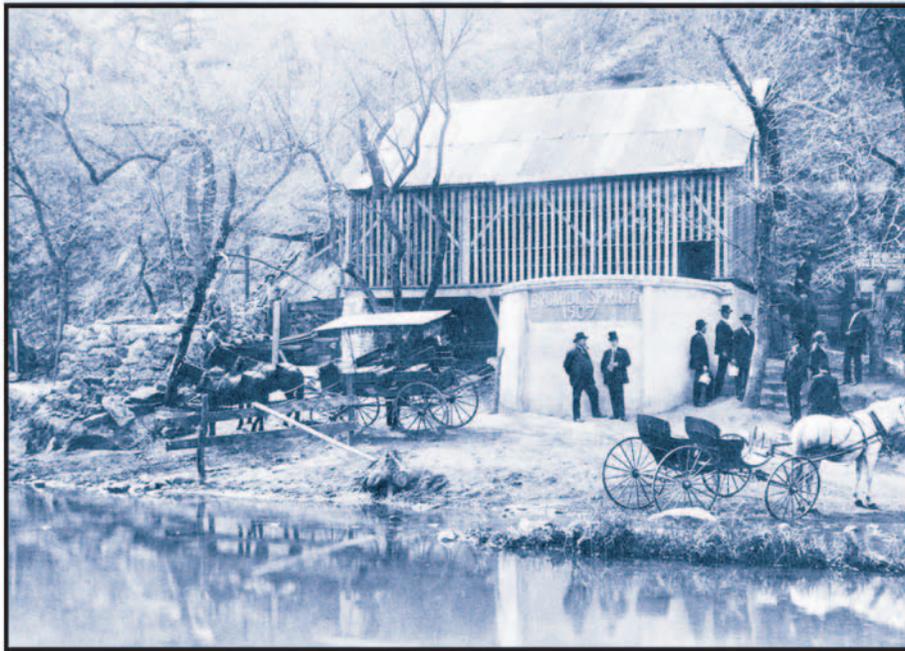
Figure 3. Vault of Bromide Springs in Chickasaw National Recreation Area a) about 1910 (National Park Service photograph) and b) 2000 (W.J. Andrews photograph).

Figure 4. Vault of Medicine Spring in Chickasaw National Recreation Area, 2000 (W.J. Andrews photograph).

shallow, very gently sloping to steep, well-drained, loamy soils formed on material weathered from tilted limestone, limestone conglomerate, and rock outcrops (Watterson and others, 1984). These soils are underlain by poorly sorted, cobbly alluvium of Quaternary age along Rock Creek valley and by limestone conglomerates and sandstones of the Vanoss Group of late Pennsylvanian age along the walls of the creek valley (Hanson and Cates, 1994; and Fairchild and others, 1990).

The study area is about 5 miles north of the Arbuckle Mountains, which have been subjected to complex faulting, folding, and deformation of rocks. Much of the mineralized water flowing from the springs near Sulphur is recharged in the Arbuckle Mountains (Hanson and Cates, 1994). Eroded parts of those mountains have formed a land surface characterized by gently rolling hills dissected by streams incised in ravines (Hanson and Cates, 1994). The Vanoss Group in the study area is underlain by shales of Ordovician or Mississippian age, which are underlain by sandstones and limestones of the Simpson and Arbuckle Groups of Ordovician and Cambrian age (Fairchild and others, 1990; Miser, 1954). The Arbuckle-Simpson aquifer, which comprises the saturated sections of the Simpson and Arbuckle Groups, is the source of water to wells and springs in the study area (Hanson and Cates, 1994). There are numerous faults and joints in rocks underlying the study area caused by structural deformation associated with the Arbuckle uplift. Those faults and joints may serve as conduits for mineralized water, originally recharged in the Arbuckle Mountains, that seeps from springs and flows from flowing artesian wells (Fairchild and others, 1990).

Tortorelli (2000) reported that in Murray County in 1995, an estimated 2.19 million gallons per day of ground water were withdrawn for all uses and 12.21 million gallons per day of surface water were withdrawn for all uses. An estimated 3.75 million gallons per day were withdrawn from the Arbuckle-Simpson aquifer in 1995 (Tortorelli, 2000). Hanson and Cates (1994) estimated flows of free-flowing artesian wells in the area to be about 19,700 gallons per minute (28.4 million gallons per day). Many of the well discharges listed in that report were reported in the 1940s. Closing of numerous resorts, decreases in pressure heads, and efforts to cap free-flowing artesian wells probably have stopped or decreased discharges from many of those wells. Cessation or decreases in the flows of many springs that flowed in the early 1900s is probably due to decreases in pressure heads caused by discharges from free-flowing artesian wells in the area.

Rock Creek (figs. 1 and 5), incised into the Vanoss Group conglomerates next to Bromide and Medicine Springs, may be the primary source of microorganisms or other biological matter in these springs through interactions between ground water and surface water. Rock Creek, which is used for recreation, passes through or near rangeland, livestock holding pens, industrial property, and the City of Sulphur. The U.S. Geological Survey has operated a continuous streamflow gaging station at Sulphur (station 07329852) on Rock Creek about 1/2 mile downstream from Medicine Spring (fig. 2) since October 1, 1989. Rock Creek is a primary tributary for Lake of the Arbuckles (fig. 1), the primary attraction for visitors to the recreation area, which is located about 2 miles south of the springs.

Visual inspection of the masonry wells or vaults encasing the spring orifices in the Vanoss Group conglomerates in May 1998 indicated that water in these vaults was standing as much as 15 feet above the level of Rock Creek, and that non-functioning drawpipes in the vaults and supply lines partially buried in the bed of Rock Creek appeared to be intact. Those features indicated potential feasibility of resuming pumping from these springs at minimal cost, providing that these springs could produce yields sufficient to supply adequate quantities of water to the pavilion, and the if quality of the springs was acceptable or treatable at minimal cost.

METHODS

Sampling procedures and water-quality analyses

Elevations of water in the spring vaults were measured from the tops of the concrete casings, using electronic water-level measurement probes on cables marked in meters and centimeters. Water levels on the edge of the stream near Bromide and Medicine Springs were surveyed to an accuracy of 0.01 foot on September 28, 2000. Six water levels recorded at the Rock Creek at Sulphur gage (station number 07329852) from February to September 2000 were

Figure 5. Rock Creek near Bromide Spring in Chickasaw National Recreation Area, 2000 (W.J. Andrews photograph).

used to estimate stream levels at the springs on other sampling dates. It was assumed that the differences in water levels between the stream near the springs and at the gage were similar to the differences recorded on September 28, 2000. Differences in geometry of the stream channels and ground-water/surface-water interactions probably cause some differences in relative stream elevations between the sites. Staff gages were not installed near the springs on Rock Creek for aesthetic reasons, the possibility of damage from visitors in that busy crossing area, and to minimize disruption of the graveled streambed and stream bank.

Water samples were collected from the spring vaults and Rock Creek by pumping with peristaltic pumps or submersible pumps constructed of stainless steel and Teflon, the intakes of which were lowered into the vaults. Water samples were analyzed for specific conductance, pH, water temperature, and dissolved oxygen concentration during purging using methods described by Wilde and Radtke (1998). Specific conductance was measured using a YSI model 30 conductivity meter or a Hydrolab Reporter sonde, both with automatic temperature compensation. The conductivity meter was calibrated daily using standard conductivity solutions prepared by the U.S. Geological Survey Water-Quality Service Unit in Ocala, Florida, that bracketed the expected field values. pH was measured using a portable Orion 250A pH meter and Ross combination probe or a Hydrolab Reporter sonde, both having automatic temperature compensation. pH meters were calibrated daily before starting field measurements using commercially prepared buffer solutions (7.0 and 10.0) that bracketed the expected field pH values. Meter calibration was subsequently corroborated using a third buffer solution (4.0). Water temperature was measured to the nearest 0.1 degree Celsius using an electronic thermistor calibrated with a National Institute of Standards and Technology standardized glass and mercury thermometer. Dissolved oxygen concentrations were measured with a YSI model 57 meter, using calibration procedures described by Wilde and Radtke (1998).

After stabilization of water property values to within 5 percent of preceding values during purging, 1-liter water samples collected for fecal-indicator bacteria analyses were decanted into sterilized (autoclaved) nalgene bottles. Those bottles were immediately chilled to 4 degrees Celsius on ice and transported to the laboratory at the Oklahoma City office of the U.S. Geological Survey within 6 hours for culturing by membrane filtration and incubation, as

described in Britton and Greeson (1987) and Wilde and Radtke (1998). Filter cartridges used to collect samples of *Giardia* and *Cryptosporidia*, microparticulates and total enteric culturable viruses were sealed in multiple Ziploc bags and shipped on ice to the University of Iowa Hygienic Laboratory, Iowa City Iowa. Staff at that laboratory conducted analyses for *Giardia* cysts, *Cryptosporidia* oocysts, other microparticulates, and total culturable enteric viruses in selected samples using culturing and counting methods specified by Faut and others (1996).

To determine the quantity of water typically discharged from the Vendome well (cover and figs. 2 and 7), a controlled flowing artesian well in the recreation area, flow from the well was measured on September 28, 2000, using methods described by Buchanan and Somers (1969).

Quality-control sampling

Two replicate samples were collected in addition to the 18 water-quality samples. Replicate samples consist of two samples collected from the same source during the same sampling event and analyzed in the same manner. Replicate samples, collected sequentially, are used to determine reproducibility of sampling procedures and laboratory analytical methods. Relative percent difference between a water-quality sample and replicate sample is calculated as follows:

$$RPD = \frac{|C_1 - C_2|}{\left(\frac{(C_1 + C_2)}{2}\right)} \times 100 \qquad (1)$$

where RPD is the relative percent difference, C_1 is the concentration of the water-quality sample, and C_2 is the concentration of the replicate sample. Lesser RPD's indicate better consistency of sampling and analytical procedures. In addition, replicate samples were cultured for most samples to determine analytical variability, as described in Britton and Greeson (1987). The RPD's of the collected samples ranged from 15 to 49 percent (Appendix 1), which is not unusual for bacteria.

Two equipment blank samples were processed for analyses of fecal-indicator bacteria counts to verify the effectiveness of cleaning procedures of pumps and tubing and processing procedures. Volumes of water needed and high costs of the protozoa, microparticu-

late, and virus analyses precluded collecting blank samples for those constituents. Equipment used for collection of those constituents had been thoroughly precleaned and sterilized at the University of Iowa Hygienic Laboratory. The equipment blanks were prepared at the Oklahoma City office of the U.S. Geological Survey by processing deionized tap water in exactly the same manner as the field water-quality samples. Two equipment-blank samples were collected by pumping blank water through pumps and tubing used to collect field samples. Data from analyses of the equipment blanks indicate that cleaning procedures of field equipment were adequate to prevent cross contamination of samples by fecal-indicator bacteria (Appendices 1 and 2).

HYDROLOGY

Streamflow

The streamflow gaging station at Rock Creek at Sulphur (station 07329852), which has been in operation since October 1989, is located about 1/2 mile downstream of Medicine and Bromide Springs (fig. 2). Daily mean streamflow has been decreasing at the gaging station, with the rate of decrease becoming greater since 1998, based on a locally-weighted scatterplot smoothing (LOWESS) curve (Cleveland and McGill, 1985; Cleveland, 1985) (fig. 6). The LOWESS curve for daily mean streamflows at that station decreased from 65 cubic feet per second in 1990 to about 11 cubic feet per second in 2000 (fig. 6). From 1989 to 2000, the LOWESS curve for monthly precipitation data collected by the National Weather Service at Chickasaw National Recreation Area decreased from 3.6 inches per month to 2.6 inches per month (fig. 6). Decreases in streamflow of Rock Creek probably are due to the combination of less rainfall from 1990-2000 (National Climatic Data Center, 2001) and decreased spring flow caused by reductions in pressure heads in the Arbuckle-Simpson aquifer because of free-flowing artesian wells, increased pumping from other wells, or other unknown causes, as described by Hanson and Cates (1994). The controlled-flowing Vendome well (fig. 7), which was redrilled in 1998, was discharging 1.4 cubic feet per second (907,200 gallons per day) from the Arbuckle-Simpson aquifer on September 28, 2000, which is similar to the discharges reported by Hanson and Cates (1994). Hanson and Cates (1994, p. 25) reported

16 flowing wells in the vicinity of Sulphur in 1987. It is not known how many flowing artesian wells were in existence in the area in 2000.

The Rock Creek at Sulphur gage (fig. 2) recorded a stream stage of 5.52 feet simultaneous to surveying of water levels in the Rock Creek near Bromide and Medicine Springs on the morning of September 28, 2000. Surveyed elevations indicated that Rock Creek was 13.93 feet below the elevation of the top of the Bromide Spring vault and 14.78 feet below the elevation of the top of the Medicine Spring vault on that day. Records indicate that on April 26, 1990, the instantaneous peak stage at the Rock Creek at Sulphur gage was 14.4 feet higher than on September 28, 2000, indicating that peak flows in Rock Creek may come close to inundating the Bromide and Medicine Spring vaults. In late March 2000, the stage of the stream at the gage nearly reached 12 feet, whereas the stage was about 5.5 feet during much of the rest of the year (fig. 8). The morphology of the stream channel and gains and losses in streamflow between the springs and the gage likely cause some differences in relative stages and changes in stages at those locations. Substantial increases in stream stage are likely to induce surface-water movement into the conglomerate in which the creek is incised and the spring vaults are set. Annual stream-stage peaks in the 1990s were 4.47 to 11.98 feet above the stage recorded at the gage on September 28, 2000.

The water levels in the Bromide Spring vault were 5.5 to 7.5 feet higher than those in the adjoining segment of Rock Creek during four of the sampling events (fig. 8), indicating only periodic probability of mixing between this spring and the adjoining segment of Rock Creek when the spring was sampled. The water levels in Medicine Spring vault were generally within 1 foot of those in the adjacent segment of Rock Creek and the water level in the creek was higher than that in the spring vault for 2 of the 4 water-level measurements, indicating a greater chance of periodic mixing with water seeping from Rock Creek into the stream-bank alluvium and about 6 feet of the adjoining Vanoss conglomerate separating the spring vault from the creek. Another possible conduit for flow of stream water into the spring vaults, particularly for Medicine Spring, would be openings or breaks in the pipes laid from the springs, underneath the bed of the creek, to
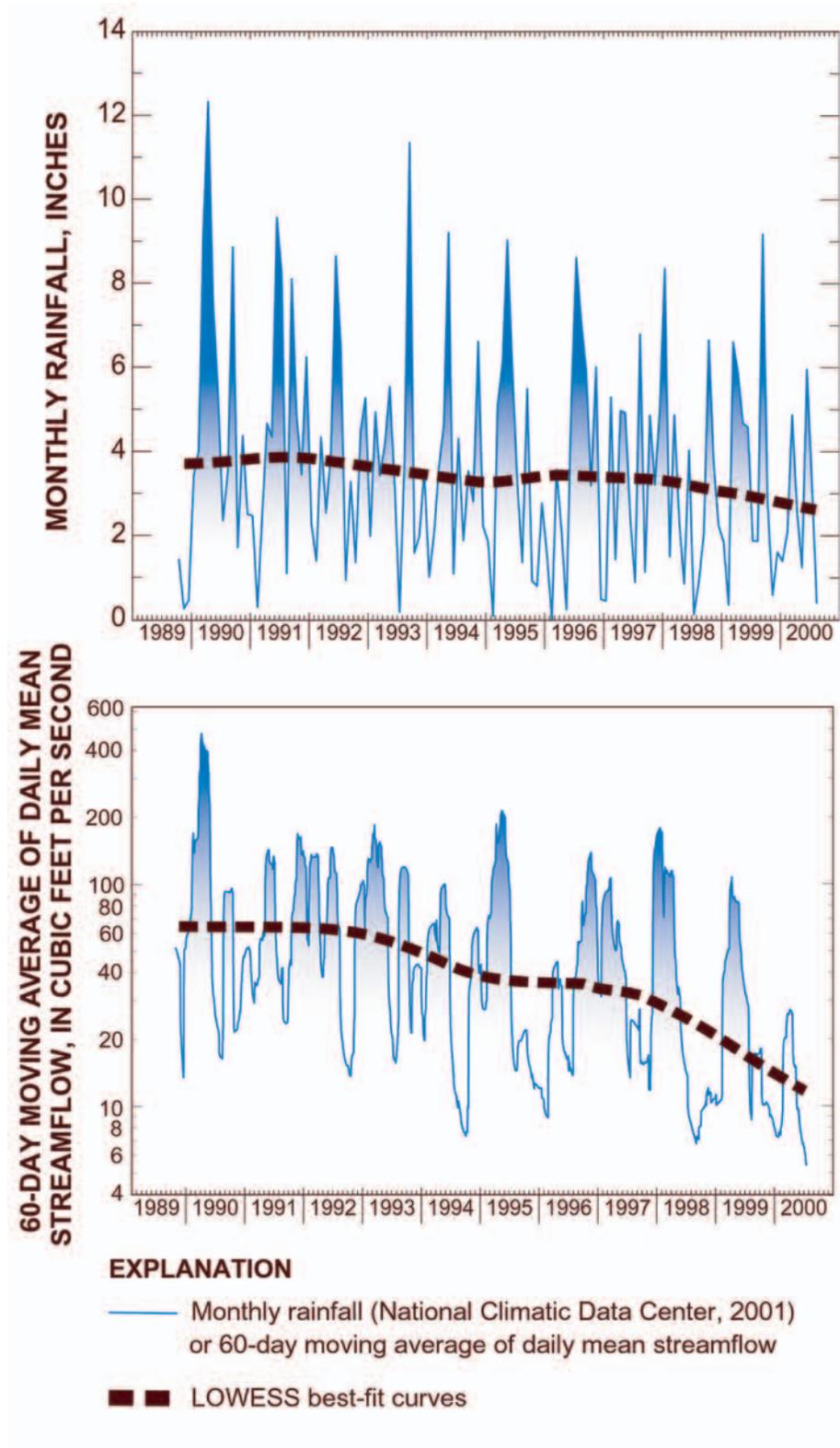
Figure 6. Monthly rainfall at Chickasaw National Recreation Area and 60-day moving average of daily mean streamflow of Rock Creek at Sulphur, Oklahoma, gage, October 1989 to August 2000.

**Figure 7.** Vendome Well in Chickasaw National Recreation Area, 2000 (W.J. Andrews photograph).
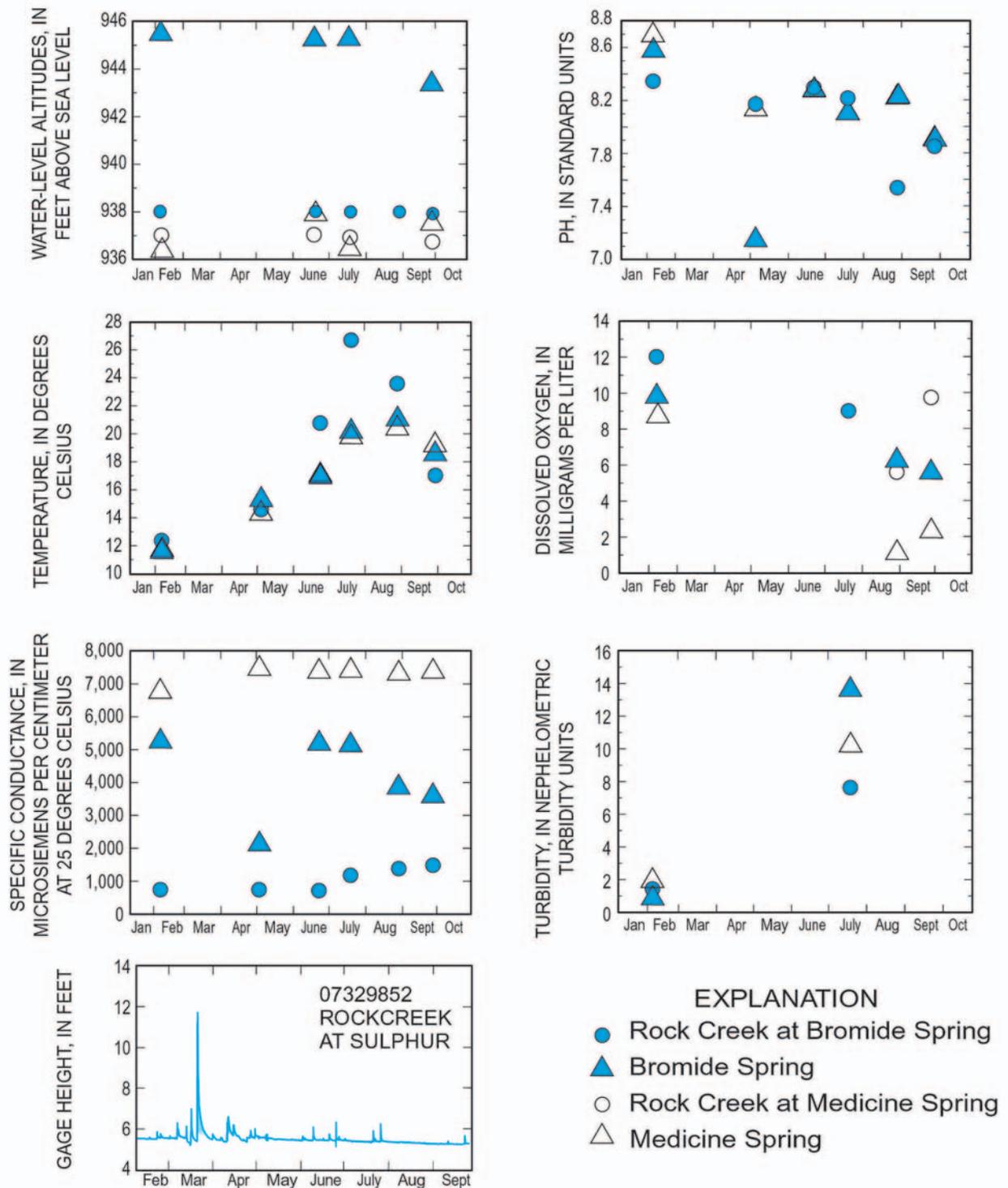
Figure 8. Water property values measured in Rock Creek, Medicine Spring, and Bromide Springs, 2000.

the pavilion. The integrity or condition of those buried pipes are unknown.

Although most peak streamflows are unlikely to inundate the spring structures, periodic rises in creek levels of 10 feet or more may induce surface-water to flow into the alluvial materials in which the spring vaults are constructed, leading to increased likelihood of surface-water seeping into the vaults, either through cracks in the concrete or through the conglomerate at the bottom of the vaults. Such seepage could carry sediments and biological contaminants from the creek into the spring vaults.

Spring yields

Hanson and Cates (1994) reported that many of the springs reported to flow earlier in the 20th century had dried up or had substantially decreased flows. Recreation area personnel were not certain whether piping of spring water to Bromide Pavilion had been discontinued in the 1970s because of decreasing spring yields, contamination of the spring water by fecal-indicator bacteria, perceived liability of serving spring water to the public, costs and labor associated with chlorinating that water, or some combination of all these factors (Ron Parker, National Park Service, oral commun., 1999).

After determining that the rate that the springs recovered from pumping was too slow for long-term pumping tests, recovery tests after drawdowns were made. Following the July sampling event after the spring vaults had been pumped nearly dry, National Park Service personnel periodically measured recovery of water levels in the springs to evaluate yields. Those data, in combination with measurements of the volumes of the spring vaults, produced estimates of possible sustainable yields from the springs.

The earliest recording of spring yields, as reported by Gould (1906), was that Bromide Spring flowed at 1 gallon per minute and that Medicine Spring flowed at 0.5 gallon per minute (table 1). As shown on figure 9, water flowed into the Medicine Spring vault at rates of less than 4.0 to 340 gallons per day (less than 0.01 to 0.24 gallon per minute) after drawdown, whereas the quantity of water flowing into Bromide Spring after drawdown ranged from less than 1 to 309 gallons per day (less than 0.01 to 0.21 gallon per minute). The maximum yields during recoveries, which may best simulate hydraulic conditions prior to

construction of the vaults, are less than historically reported flows. Possible reasons for decreased yields in the 20th century from those springs include:

1. decreased pressure heads in the Arbuckle-Simpson aquifer from free-flowing artesian wells, greater withdrawals from other wells, greater evapotranspiration from introduced trees, and decreases in rainfall;

2. constriction of the spring conduits by natural collapses, precipitation of minerals in the conduits (which may be worsened by having spring water standing for long periods in the concrete vaults), plugging by debris deposited by surface-water inundation, blockage of the natural conduits by the spring vaults (no conduit openings were visible in the vaults after they were pumped down), or clogging with natural asphaltic materials (equipment from several long-term monitoring wells have been reported to be covered with asphalt upon removal); or

3. other unknown causes.

The small amounts of water obtainable from the springs indicate that supplying water to large numbers of visitors may be problematic, even with secondary storage tanks at the pavilion. There could be intermittent shortages of spring water during the summer season when visitation peaks and water levels tend to be at the lowest point of the year. The quantity of water available from the springs may limit possibilities for the restoration of these springs as sources of mineralized water for visitors.

An additional potential limitation to piping water from Medicine Spring to the pavilion is the presence of a large, overhanging, undermined cliff of calcareous conglomerates of the Vanoss Group. In September 2000, there were fractures on the sides of the overhanging cliff, indicating potential separation and collapse (fig. 10). A block of similar material of about 1,000 cubic feet has fallen into the creek about 100 feet downstream from this spring (fig. 10). A similar collapse of this cliff could crush and bury the spring vault and any associated plumbing.

An alternative to restoration of the piping of the springs would be completion of wells in the Arbuckle-Simpson aquifer that could provide adequate quantities of mineralized water from similar strata supplying water to the springs. The wells could be situated to be less vulnerable to contamination by surface water and other hazards inherent in the creek valley.

Table 1. Historic discharges and water-quality analyses of Bromide and Medicine Springs

[data from USGS National Water Information System database, concentrations in milligrams per liter, unless otherwise noted, gpm, gallons per minute; NA, not analyzed]

Date	Dis-charge (gpm)	pH (stan-dard units)	Hard-ness, as CaCO₃	Alka-linity, as CaCO₃	Dis-solved solids	Cal-cium	Mag-ne-sium	Sodi-um	Po-tas-sium	Sul-fate	Chlo-ride	Fluor-ide	Bro-mide	Silica	Ni-trate, as nitro-gen	Am-monia, as nitro-gen	Fer-ric oxide	Iron
Bromide Spring																		
1906	1	NA	NA	NA	NA	61	20	1,700	6.0	42	2,000	NA	12.4	30	NA	NA	8.0	NA
10/01/63	NA	6.9	232	472	4,340	42	28	NA	NA	40	2,000	1.0	NA	NA	0.8	0.55	NA	<1
7/02/87	NA	NA	249	NA	3,960	50	30	1,300	NA	48	2,000	NA	NA	NA	NA	NA	NA	NA
Medicine Spring																		
1906	0.5	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
10/01/63	NA	7.5	212	NA	4,360	43	25	NA	NA	68	1,120	1.5	NA	NA	0.1	13	NA	<1
7/02/87	NA	NA	318	NA	4,520	68	36	1,490	NA	14	2,370	NA	NA	NA	NA	NA	NA	NA
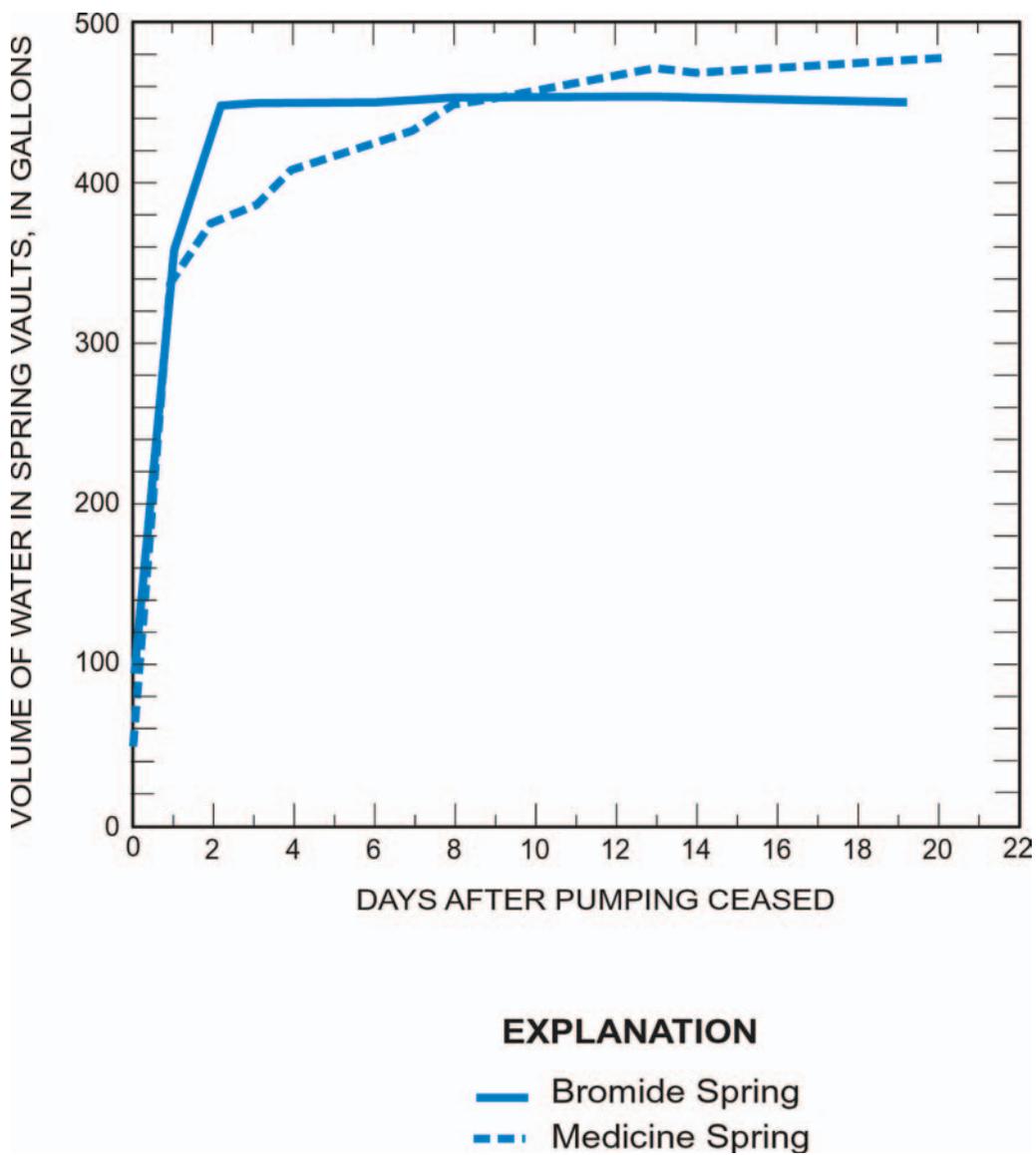
Figure 9. Relation between volume of water in Bromide and Medicine Springs vaults and time after pumping ceased, July-August, 2000.
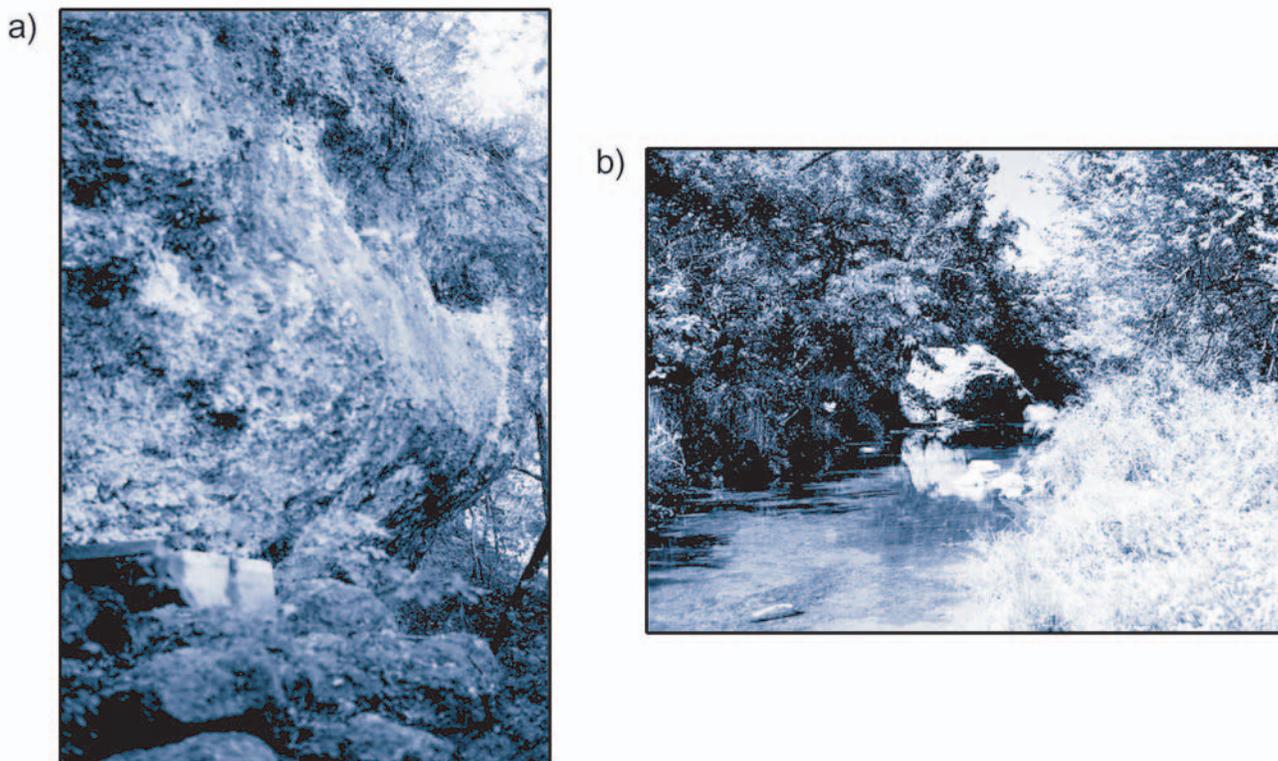
Figure 10. (a) The cliff overhanging Medicine Spring (W.J. Andrews photograph), and (b) a collapsed block of calcareous conglomerate in Rock Creek about 100 feet downstream of Medicine Spring, September 2000 (W.J. Andrews photograph).

WATER QUALITY

Water samples were analyzed in the field for specific conductance, pH, temperature, and dissolved oxygen concentration. Water samples were collected for determination of counts of fecal-indicator bacteria *(E. col*i, fecal coliform, and fecal streptococcal), for protozoan cysts *(Giardia lamblia* and *Cryptosporidium parvum*), and for total culturable enteric viruses to determine the suitability of Bromide and Medicine Springs for drinking, and to determine possible hydraulic connections between the springs and Rock Creek. The bacteria analyzed may directly cause disease or indicate the possible presence of other disease-causing microorganisms in water. Protozoan cysts and oocysts can survive for extended periods in water and directly cause severe gastrointestinal distress, potentially fatal if untreated in the very young, the aged, and people with compromised immune systems (U.S. Food and Drug Administration, 2001a and b). Unlike bacteria, which generally must be ingested by the hundreds or thousands to cause illness, ingestion of one or a small number of protozoan cysts or oocysts may be sufficient to cause illness (U.S. Food and Drug Administration, 2001a and b).

Historic Major Ion Concentrations

Although not synchronous with the water-quality sampling conducted in 2000, historic water-quality data from springs and creeks in the recreation area can provide useful information about the degree of interconnection and similarity or dissimilarity of those resources. Historic water-quality data collected from Bromide and Medicine Springs by the U.S. Geological Survey indicate that the water from these springs is relatively hard, with substantial concentra-

tions of sodium, sulfate, and chloride (table 1, fig. 11). For comparison, the last analyzed water sample collected from Vendome Well in 1987 had a greater proportion of calcium and lesser proportions of sodium and chloride than water from these two springs (fig. 10).

Surface-water samples collected from the area generally became less similar to ground-water samples in the downstream direction. Five water samples collected by the U.S. Geological Survey from Rock Creek north of Sulphur (station number 07329843) (fig. 1) from 1958-1960, located 2 miles upstream from the springs, were hard, with substantial concentrations of sodium, sulfate, and chloride (table 2, figs. 1 and 11). Water samples collected at the Rock Creek at Sulphur gage from 1990 to 1995 were relatively alkaline, and had moderate concentrations of sodium, sulfate, and chloride (table 2, fig. 11). Arsenic, iron, manganese, and zinc also were detected (table 2). Assuming that stream-water chemistry did not change appreciably between sampling periods, concentrations of most major ions tend to decrease downstream, indicating that mineralized spring-water is not a major contributor of water or dissolved constituents along that section of the creek (table 2). Decreases in concentrations of sodium, sulfate, and chloride with increased streamflow (fig. 12) at the Rock Creek at Sulphur gage (site number 07329852) also indicate that mineralized spring water has the greatest effect on surface-water quality in the basin during dry or low-flow periods. Bromide and Medicine Springs had much greater concentrations of sodium and chloride than the samples from Rock Creek (tables 1 and 2, fig. 11). There are not sufficient major-ion data from these springs to determine fluctuations in major-ion concentrations related to changes in flow in Rock Creek.

Water Properties

Water properties were measured to compare water quality in Rock Creek and in the springs and to investigate possible hydraulic connections between the springs and the creek. Similarities between water property values in these two groups would indicate possible hydraulic connection between the springs and the stream (and greater risk of contamination by bacteria, and other microorganisms from the stream), whereas substantial differences in the values of these properties would indicate lack of interaction between the springs and the creek.

There was a rapid rise in gage height at the Rock Creek at Sulphur, Oklahoma, gage in late March 2000 (fig. 8). Specific conductance and pH of water from Bromide Spring decreased substantially from previous values in water collected on May 2, 2000, (fig. 8, table 3). Such changes may be due either to ground-water infiltration along a shallow flowpath or to mixing with less mineralized runoff-dominated stream water that seeped into the bank and the spring vault during that high flow event. Lesser specific conductances in Bromide Spring also may indicate water having a shorter residence time and shorter flowpath in the Arbuckle-Simpson aquifer than water from Medicine Spring.

Water samples from both springs and the creek were more turbid in July than in February (table 3). In addition to natural fluctuations, turbidity may be affected by location of the pump, stirring up of bottom sediments during sampling, recent storms inducing runoff to the creek, or recreational activities upstream in the creek.

Values of pH, temperature, and dissolved oxygen concentrations were not substantially different between the springs and the creek (fig. 8, table 3). Springs fed by ground water that has circulated deeply in an aquifer have fairly constant pH, temperature, and chemistry. In contrast, pH, temperature, and chemistry of streams is more variable due to influences such as runoff, plant growth, and solar radiation. There was a general decrease in pH values from about 8.6 to 7.9 with time at the sites, with the greatest fluctuations occurring in Bromide Spring (fig. 8, table 3). Water temperatures appear to be associated with colder air temperatures in the winter and warmer air temperatures during summer (fig. 8, table 3).

Fecal-Indicator Bacteria

Counts of fecal indicator bacteria, including *E. coli*, fecal coliform, and fecal streptococcal, were made in water samples from six sampling events at Bromide Spring, Medicine Spring, and Rock Creek near Bromide Spring (table 3). The greatest bacteria counts generally were in water samples from Rock Creek (fig. 13, table 3). The U.S. Environmental Protection Agency has a maximum contaminant level for drinking water of no more than 5 percent of
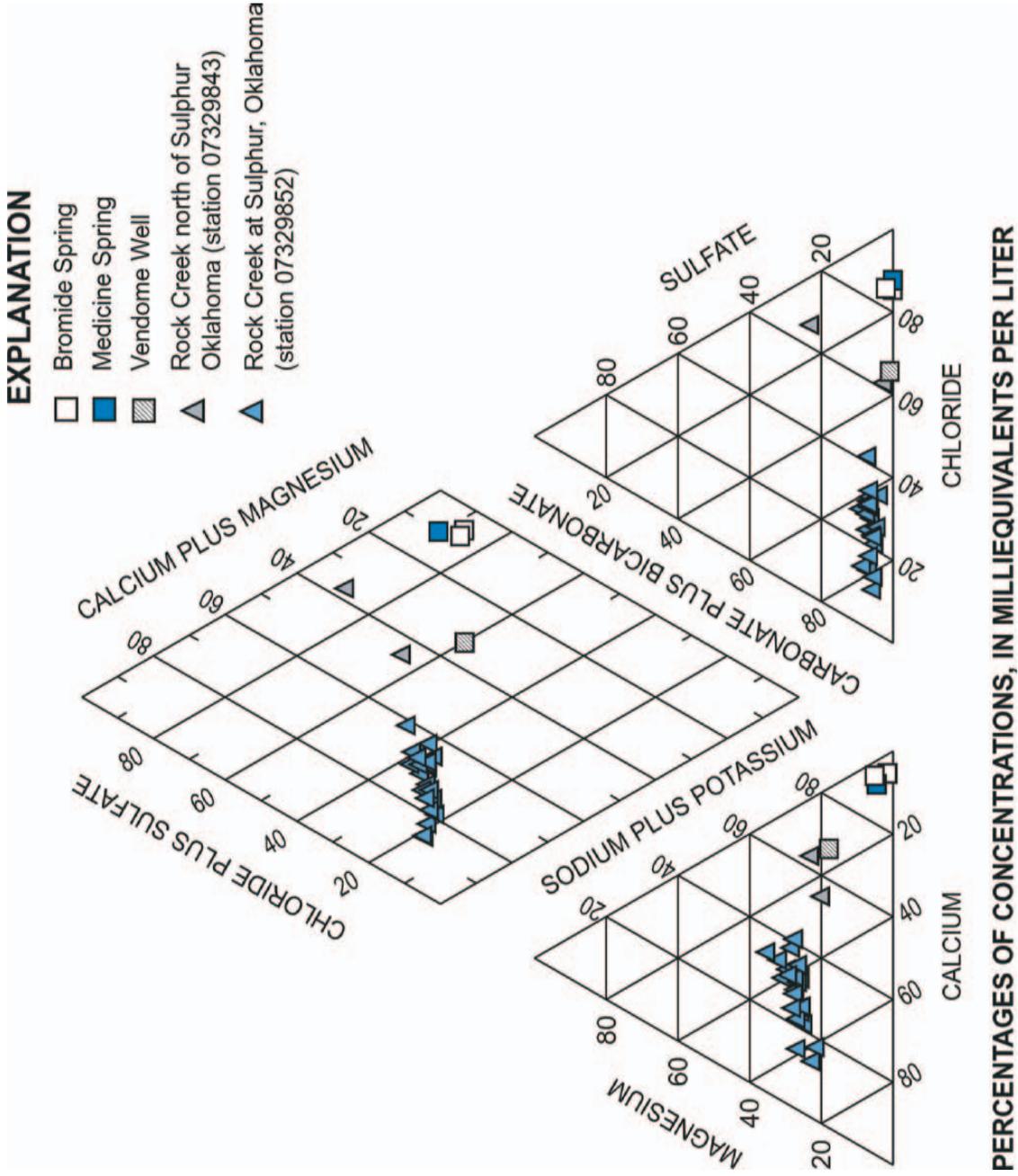
Figure 11. Ratios of major ions in water samples from Bromide and Medicine Springs, Vendome Well, and Rock Creek north of and at Sulphur, Oklahoma, 1906-1995.

Table 2. Summary of historic discharges and water-quality analyses of Rock Creek and Vendome Well

[Data from USGS National Water Information System database, concentrations in milligrams per liter, unless otherwise noted, <, less than; µg/L, micrograms per liter]

Parameter	Number of samples	Range	Mean	Median
Rock Creek north of Sulphur (station number 07329843)				
Dates		1958-1960		
Discharge (cubic feet per second)	3	0.11 - 0.97	0.64	0.85
Specific conductance (microsiemens at 25 degrees Celsius)	5	1,120-2,100	1,500	1,300
pH (standard units)	5	8.2 - 8.3	8.24	8.2
Water temperature (degrees Celsius)	3	17.2 - 27.8	21.5	19.4
Acid neutralizing capacity, as $CaCO_3$	5	112 - 218	150	113
Dissolved solids	2	64 - 1,090	580	580
Carbon dioxide	5	1.1 - 2.7	1.72	1.4
Calcium	5	34-66	53	54
Magnesium	5	25 - 48	36	35
Sodium	5	143 - 278	200	174
Sulfate	2	20 - 179	100	100
Chloride	5	235 - 480	334	278
Nitrate-nitrogen	2	0.14 - 0.27	0.20	0.20
Rock Creek at Sulphur (station number 07329852)				
Dates		1990 - 1995		
Specific conductance (microsiemens at 25 degrees Celsius)	76	434 - 959	720	770
pH (standard units)	77	7.8 - 9.1	8.4	8.3
Temperature (degrees Celsius)	78	7.6 - 27.2	20.4	20.5
Dissolved oxygen	78	7.6 - 13.9	10.5	10.4
Carbon dioxide	23	<0.3 - 8.2	2.6	2.1
Acid neutralizing capacity, as $CaCO_3$	24	151 - 269	245	249
Calcium	24	39 - 75	64	66
Magnesium	24	9.1 - 35	24	25
Sodium	24	11 - 88	47	51
Potassium	24	1.9 - 4.5	2.8	2.8
Sulfate	25	11 - 26	17	18
Chloride	25	14 - 140	74	76
Fluoride	25	<0.1 - 0.5	0.22	0.2
Silica	25	6.1 - 11	8.6	8.6
Ammonia-nitrogen, dissolved	10	<0.01 - 0.03	.02	.02
Nitrite-nitrogen, dissolved	10	<0.01 - 0.03	0.01	0.01
Organic- plus ammonia-nitrogen, total	23	<0.2 - 0.7	0.3	0.2
Nitrate- plus nitrite-nitrogen, total	12	<0.05 - 0.30	0.11	0.02
Orthophosphorus-phosphorus, total	7	<0.01 - 0.07	0.02	0.01

Table 2. Summary of historic discharges and water-quality analyses of Rock Creek and Vendome Well—Continued

| Parameter	Number of samples	Range	Mean	Median
Phosphorus, total	22	<0.01 - 0.12	0.03	<0.01
Arsenic (µg/L)	23	<1 - 1	<1	<1
Boron (µg/L)	24	0.30 - 150	94	100
Chromium, total (µg/L)	23	<1 - 18	4	2
Copper, total	24	<1 - 10	4	<1
Iron	24	<3 - 46	18	10
Manganese	24	2.0 - 35	13	13
Selenium	23	<1 - 8	1	<1
Zinc	25	<10 - 77	13	<10
Vendome Well (station number 07329851)				
Dates		1955-1990		
Discharge (cubic feet per second)	21	1.1 - 1.7	1.3	1.3
Specific conductance (microsiemens at 25 degrees Celsius)	25	2,250 - 3,750	2,430	2,350
pH (standard units)	21	6.35 - 8.20	7.22	7.25
Water temperature (degrees Celsius)	24	14.5 - 24.5	19.6	19.5
Acid neutralizing capacity (as bicarbonate)	4	260 - 330	300	305
Dissolved solids	3	1,170 - 1,200	1,190	1,200
Calcium	4	40 - 86	62.5	62.0
Magnesium	3	26 - 37	33.3	37.0
Sodium	1	252	252	252
Sulfate	3	<1 - 30	18.7	26
Chloride	4	350 - 560	475	495
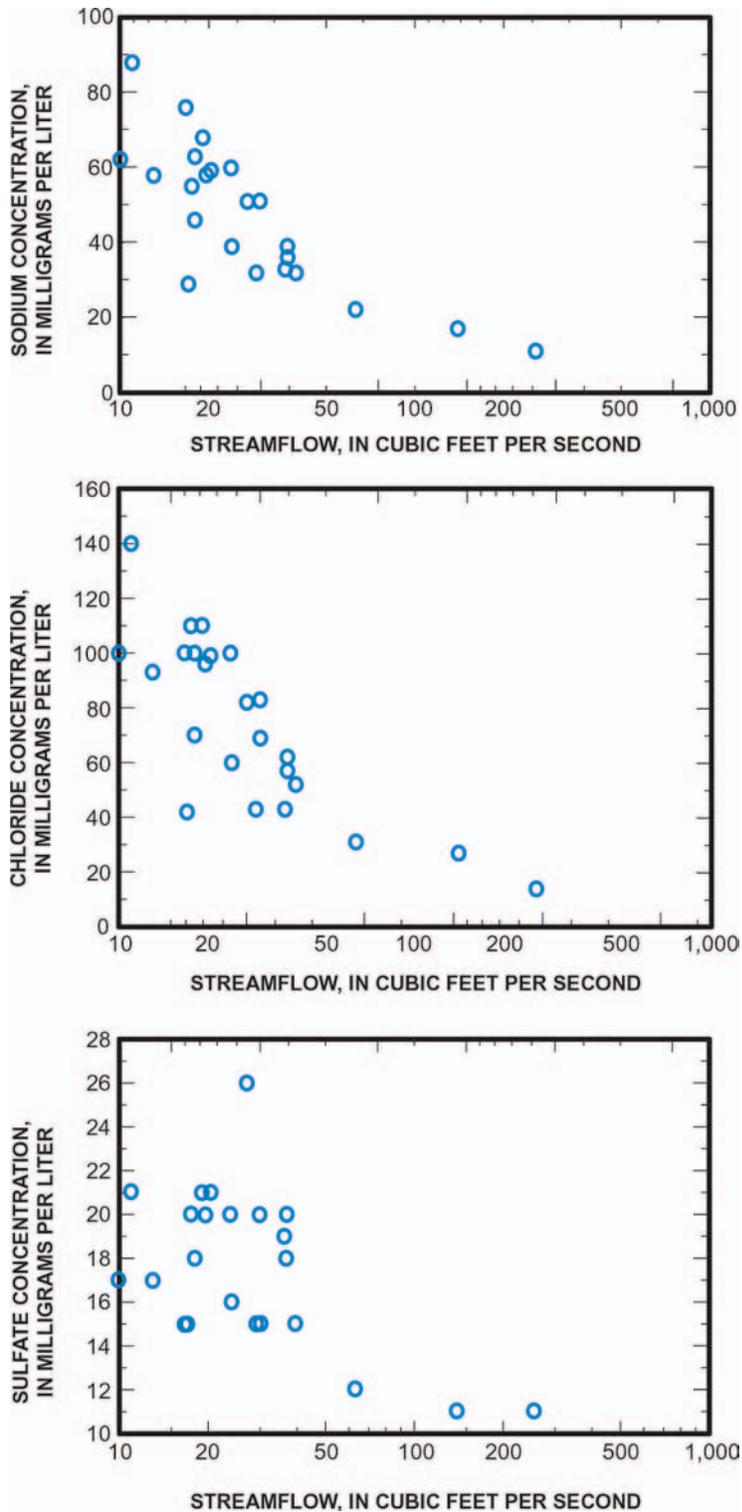
Figure 12. Relation between concentrations of sodium, chloride, and sulfate and streamflow, Rock Creek at Sulphur, Oklahoma, 1990-1995.

Table 3. Water properties, water levels, and bacteria counts, Rock Creek, Bromide Spring, and Medicine Spring in 2000

[<, not detected at reporting limit specified by corresponding number; *, estimated]

| Date	Specific conductance (microsiemens per centimeter at 25 degrees Celsius)	pH	Temperature (degrees Celsius)	Dissolved oxygen (milligrams per liter)	Turbidity (nephelometric turbidity units)	Water level (feet above mean sea level)	Fecal coliform bacteria (colonies per 100 milliliters)	Fecal streptococcal bacteria (colonies per 100 milliliters)	Escherichia coli bacteria (colonies per 100 milliliters)
Rock Creek at Bromide Spring									
2/7/00	755	8.35	12.3	12	1.44	938*	32	19	20
5/2/00	730	8.18	14.5	--	--	938*	90	140	38
6/22/00	827	8.30	20.8	--	--	938*	380	260	160
7/19/00	1,080	8.21	26.6	8.5	7.68	938*	32	38	18
8/29/00	1,440	7.53	23.7	5.6	--	938*	53	54	15
9/28/00	1,520	7.85	17.0	9.7	--	937.84	36	21	23
Bromide Spring									
2/7/00	5,310	8.60	11.8	10	1.02	945.68	45	41	<1
5/2/00	2,220	7.18	15.5	--	--	--	<1	18	<1
6/22/00	5,260	8.30	17.1	--	--	945.26	<1	46	9
7/18/00	5,160	8.12	20.3	--	13.8	945.28	<1	21	1
8/29/00	3,870	8.24	20.6	6.4	--	--	<1	9	5
9/28/00	3,700	7.93	18.9	5.8	--	943.32	<1	<1	<1
Rock Creek at Medicine Spring									
2/8/00	--	--	--	--	--	937.00*	--	--	--
5/2/00	--	--	--	--	--	937.08*	--	--	--
6/22/00	--	--	--	--	--	937.02*	--	--	--
7/18/00	--	--	--	--	--	936.86*	--	--	--
8/29/00	--	--	--	--	--	936.76*	--	--	--
9/28/00	--	--	--	--	--	936.76	--	--	--
Medicine Spring									
2/8/00	6,910	8.69	11.9	8.7	2.03	936.38	<1	<1	4
5/2/00	7,520	8.16	14.5	--	--	--	<1	<1	<1
6/22/00	7,480	8.30	17.0	--	--	938.00	<1	<1	6
7/18/00	7,500	8.12	20.0	--	10.3	936.39	<1	<1	<1
8/29/00	7,460	8.24	20.5	1.4	--	--	<1	>100	8
9/28/00	7,440	7.93	19.4	2.4	--	937.58	<1	<1	<1
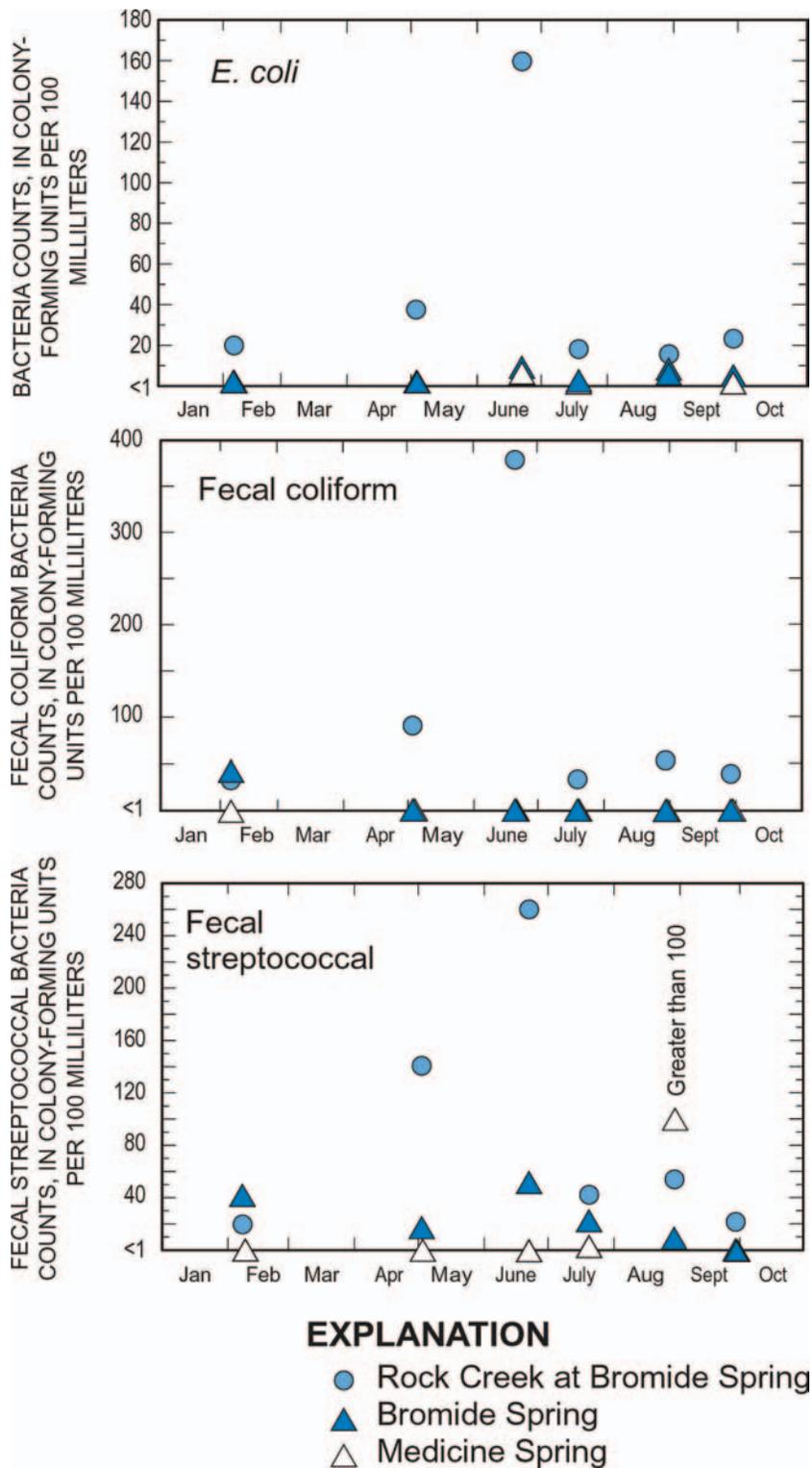
Figure 13. Fecal-indicator bacteria counts measured in water from Rock Creek, Bromide Spring, and Medicine Spring, 2000.

samples in a month containing detectable counts of total coliform bacteria (U.S. Environmental Protection Agency, 2001). That standard was routinely exceeded in Rock Creek and periodically exceeded in water from the springs (table 3, fig. 13). For utilities using surface water as a source of drinking water, the State of Oklahoma has established a Raw Water Numerical Criterion for total coliform bacteria of 5,000 colonies per 100 milliliters (Oklahoma Water Resources Board, 2000), which was not exceeded by the fecal coliform counts (fig. 13, table 3). It is not known whether counts of other types of coliform bacteria in those samples were sufficient to exceed that standard. For primary contact with surface water, the State of Oklahoma has a standard for fecal coliform bacteria of no more than 200 colonies per 100 milliliters as the geometric mean of at least five samples collected over 30 days (Oklahoma Water Resources Board, 2000). For *E. coli* bacteria, the primary contact standard is a 30-day geometric mean of 126 colonies per 100 milliliters, with no more than 10 percent of samples exceeding 235 colonies per 100 milliliters (Oklahoma Water Resources Board, 2000). There were not enough samples collected to determine 30-day geometric means of bacteria counts, but some counts of fecal coliform and *E. coli* bacteria exceeded those limits (table 3, fig. 13), particularly on June 22, 2000, which was the sampling event associated with the greatest streamflow (figs. 6, 8, and 13, and table 3). Data from the replicate (sequential) samples in Appendix 1 indicates that counts of fecal-indicator bacteria are variable over short periods of time in Rock Creek. Bacteria were not detected in either the field or replicate samples collected from Bromide Spring on September 28, 2000.

Sources of fecal streptococcal bacteria in the springs may include bacteria carried by previous inundation or induced surface-water inflow during high stream stages. Some of those bacteria also may be indigenous in the environment, surviving for extended periods in soils and water (Clesceri and others, 1998). The count of fecal streptococcal bacteria were greatest in water from Bromide Spring on June 22, 2000, whereas the counts of those bacteria in water from Medicine Spring were greatest on August 29, 2000 (fig. 13, table 3).

Protozoa and Microparticulate Analyses

Indicators of *Giardia* and *Cryptosporidium* protozoa were not detected in Rock Creek or the springs (table 4). Counts of protozoa, including forms of *Giardia* (empty cysts, cysts with amorphous structures, cysts with one internal structure, cysts with greater than one internal structure, and total cysts), and *Cryptosporidium* (empty oocysts, oocysts with amorphous structures, oocysts with internal structures, and total oocysts) were made at reporting limits ranging from 5 to 49 per 100 liters in water samples collected from Bromide and Medicine Springs in July, and from Rock Creek near Bromide Spring in February and July.

Microparticulate analyses (table 5) indicate that Bromide Spring is at least intermittently mixed or inundated by surface water, as indicated by detection of diatoms, algae, plant debris, fungi, pollen, and crustaceans. In February, water from Bromide Spring was analyzed for microparticulates, including counts of *Giardia* cysts, *Cryptosporidium* oocysts, diatoms with chlorophyll, algae with chlorophyll, insect larvae, rotifers, and plant debris. There was insufficient water remaining in Medicine Spring after initial purging, measurement of water properties, and sampling for fecal-indicator bacteria to conduct microparticulate analysis, which requires pumping a minimum of 100 gallons through filtration equipment.

Total Culturable Enteric Viruses

Counts of total culturable enteric viruses were made at reporting limits of about 1 culturable virus per 100 liters in samples collected from Bromide Spring in February and July, Medicine Spring in July, and Rock Creek near Bromide Spring in July. Virus samples were not collected from Rock Creek in February because of the unavailability of sufficient numbers of sterilized filter units and associated equipment. In February, there was insufficient water remaining in Medicine Spring and insufficient recovery of water levels to collect and sample for virus analysis from that spring.

Total culturable enteric viruses were only detected in the sample from Rock Creek near Bromide Spring collected in July (table 6). That sample was taken during the summer recreation season, when many people wade in the stream. A group of about 20

Table 4. Counts of protozoan cysts and oocysts in water samples from Rock Creek, Bromide Spring, and Medicine Spring in 2000

[<, not detected at reporting limit specified by corresponding number; all protozoa counts in cysts/oocysts per 100 liters]

Site	Date	Giardia (empty cysts)	Giardia (cysts with amorphous structures)	Giardia (cysts with one internal structure)	Giardia (cysts with two or more internal structures)	Giardia (cysts, total)	Cryptosporidium (empty oocyst)	Cryptosporidium (oocysts with amorphous structures)	Cryptosporidium (oocysts with internal structure)	Cryptosporidium (oocysts, total)
Rock Creek near Bromide Springs	2/7/00	<41	<41	<41	<41	<41	<41	<41	<41	<41
Rock Creek near Bromide Springs	7/19/00	<49	<49	<49	<49	<49	<49	<49	<49	<49
Medicine Spring	7/18/00	<5	<5	<5	<5	<5	<5	<5	<5	<5
Bromide Spring	7/18/00	<5	<5	<5	<5	<5	<5	<5	<5	<5

Table 5. Microparticulate analysis counts in a water sample from Bromide Spring on February 7, 2000

[<, not detected at reporting limit specified by corresponding number; all counts per 100 liters]

Giardia cysts	Cryptosporidium oocysts	Diatoms with chlorophyll	Algae with chlorophyll	Insects and insect larvae	Rotifers	Plant debris particles	Other materials
<38	<38	10	108	<5	<5	1,021	numerous fungal elements and spores, pollen, and crustaceans

Table 6. Total culturable enteric virus counts in water samples from Rock Creek, Bromide Spring, and Medicine Spring in 2000

[< not detected at reporting limit specified by corresponding number; MPN, most probable number; NA, not applicable]

Site	Date	Enteric virus, human, total culturable (MPN)	Identified virus
Rock Creek near Bromide Spring	7/19/00	10	Enterovirus (not *Coxsackie* group 1-6, not *Polio,* not *Enterovirus* 71, not *Echovirus* group 4, 6, 9, 11, or 30)
Bromide Spring	2/7/00	<1.0	NA
Bromide Spring	7/18/00	<1.0	NA
Medicine Spring	7/18/00	<1.0	NA

children and park rangers had waded upstream from the collection site about 45 minutes prior to collection of the sample, which entrained additional stream bottom sediments in the water column and also may have directly added to virus load to the stream. Turbidity at the time of sample collection was 7.68 nephelometric turbidity units (fig. 8, table 3). The virus in the water sample from Rock Creek was an enterovirus, which could not be classified further (table 6).

SUMMARY

The U.S. Geological Survey, in collaboration with the National Park Service, periodically sampled Bromide and Medicine Springs and the section of Rock Creek adjoining those springs in 2000 to evaluate the feasibility of obtaining adequate quantities and sufficient quality of water to resume piping spring water to Bromide Pavilion, and to evaluate microbiological contamination in Rock Creek and possible hydraulic connection between the springs and the creek.

The slow recoveries of the springs after pumping indicated that insufficient quantities of water may be available from these springs to reliably supply Bromide Pavilion. Water levels in the Bromide Spring vault were higher (5.5 to 7.5 feet) than the water level in the adjoining segment of Rock Creek, whereas the water level in the Medicine Spring vault was generally within a foot of the water level in the adjoining segment of Rock Creek during sampling days. Historical streamflow, stage, and water chemistry data indicate that these spring vaults may intermittently be flooded by neighboring Rock Creek during peak flows and that surface-water also may seep through the alluvial materials in which the spring vaults are constructed. Long-term use of Medicine Spring also may be threatened by an undercut, overhanging cliff composed of calcareous conglomerate that may collapse into Rock Creek.

Many samples from the springs did not have detectable colonies of fecal-indicator bacteria *(E. col*i, fecal coliform, and fecal streptococcal), but there was a greater incidence of detection of these bacteria in water from Bromide Spring. Those bacteria may cause disease directly or indicate the possible presence of disease-causing microorganisms. There were no detections of the disease-causing cysts of *Giardia lamblia*, oocysts of *Cryptosporidium parvum*, or culturable enteric viruses in the springs, indicating that, with treatment to kill bacteria, water from the springs might be suitable for human consumption.

The possibility of periodic inundation or mixing with surface water seeping into the conglomerate of

the Vanoss Formation into which the vaults were emplaced, relatively small yields, the physical hazard of an apparently unstable cliff overhanging Medicine Spring, and the presence of fecal-indicator bacteria and possible periodic occurrence of enteric viruses in the adjoining creek indicate that the springs may be problematic for supplying potable water.

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APPENDIX

Appendix 1. Analyses of two replicate samples collected at Chickasaw National Recreation Area, 2000

[<, less than; --, value could not be computed]

Site	Date	Constituent	Sample value	Repli-cate value	Relative percent differ-ence
Rock Creek at Bromide Spring	9/28/00	Escherichia coli bacteria	23	14	48.6
Rock Creek at Bromide Spring	9/28/00	Fecal streptococcal bacteria	21	18	15.4
Rock Creek at Bromide Spring	9/28/00	Fecal coliform bacteria	34	45	27.8
Bromide Spring	9/28/00	Escherichia coli bacteria	<1	<1	--
Bromide Spring	9/28/00	Fecal streptococcal bacteria	<1	<1	--
Bromide Spring	9/28/00	Fecal coliform bacteria	<1	<1	--

Appendix 2. Analyses of two equipment blank samples collected at Chickasaw National Recreation Area, 2000

[<, less than]

Site	Date	Constituent	Blank value	Sample value
Bromide Spring	2/8/00	Escherichia coli bacteria	<1	<1
Bromide Spring	2/8/00	Fecal streptococcal bacteria	<1	41 (2/7/2000)
Bromide Spring	2/8/00	Fecal coliform bacteria	<1	45 (2/7/2000)
Bromide Spring	9/28/00	Escherichia coli bacteria	<1	<1
Bromide Spring	9/28/00	Fecal streptococcal bacteria	<1	<1
Bromide Spring	9/28/00	Fecal coliform bacteria	<1	<1